A HISTORY OF THE DEVELOPMENT OF THE SUSPENSION BRIDGE

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A HISTORY OF THE DEVELOPMENT OF THE SUSPENSION BRIDGE

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History is the depository of great actions: the witness of the past, the example and instructor of the present and monitor of the future.---Cervantes.

PREFACE.

A noted writer has said "Proficiency in any art or science is not attained until its history is known. Many a student and designer finds, after weary hours of thought, that the problems over which he studied were considered and mastered by others, years or centuries before, perhaps with better results than his own."

*The most remarkable trend of modern thought notwithstanding the effervescent boastfulness of the present century, is an appreciation of the work done by those who have gone before.

Considering these statements it behooves the present day engineer to look into the past to help in solving the problems of the future. The writer has chosen his subject with the hope that it may prove of value to himself and whoever may read his paper.

To give a complete account of the develppment of the suspension bridge in a paper of this kind is obviously impossible. No attempt has been made here to do more than to

recount the successive steps in the development of the suspension bridge which would attract the greatest amount of attention and to supply as far as possible such facts and figures as have been and are most likely to be in demand for purposes of references.

The material used in the preparation of this paper has been drawn from current periodical literature and from writings of other engineers. A blanket reference is given of all the articles from which material has been abstracted. Many of the illustrations have been reprinted from the Engineering News, Engineering Record and other technical papers and reports.

The writer is especially indebted to Prof. M. B. Wells of the Armour Institute of Technology, for his assistance and encouragement; to Elta Virginia Savage, Librarian of the Western Society of Engineers Library and Edith M. Ford, Librarian of the Armour Institute of Technology Library, who have kindly directed his researches through the valuable volumnes under their care.

Special acknowledgement is made of the very valuable work of Miss Esther Gillan, and of the writer's sister, Mrs. J. L. Theisen, who have assisted in the preparation and arrangement of the manuscript.

Herbert A. Mann.

*J. Elfreth Watkins, Assoc. Am. Soc. C. E.

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"THE EVOLUTION OF THE
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Bridges have existed since the dawn of history. Primitive races were content with rude structures made of logs or trees thrown across the streams, or by ropes made of vines or creepers forming large cables, to span the larger rivers and valleys. Although the earliest application, by means of the suspension principle for bridges, probably far antidates extant records of the mechanic arts of the ancients, we are compelled to come down to comparatively modern times for authentic accounts of the earliest known suspension bridges. Wadell in his chapter on the Evolution of Bridge Engineering states that to go back to the beginning of bridge building one must revert to the days when our arboreal ancestors formed living chains of their bodies. They held each other with arms, legs and tails, thus constructing suspension bridges across the water, from the over hanging branches of opposite trees, which enables their tribe to pass over in safety to the other side.

This custom is still practiced by their undeveloped descendants who reside today in South American forests.

The suspension principle of bridging rivers and valleys was used in remote ages in China, Japan, Thibet, and by the Dykas of Borneo, the Aztecs of Mexico, and the natives of Peru and other parts of South America. These primitive bridges were very light, requiring no piers; were economical, and are still to be found in Peru, parts of China, India and Ireland.

De Ulloa, writing in 1752, describes suspension bridges known in South America before its discovery by Europeans. These bridges were made by twisting together creepers to form large cables, which spanned rivers and valleys. Four such cables bound together and covered with reeds constituted the footway, while two others served as hand rails. Another type called the "tarabita" was capable of transporting beasts of burden as well as people. This type consisted simply of one large cable six or eight inches in diameter formed of twisted strands of creepers or of oxhide thongs. One end of the cable was supported by a tree or post on one shore, while the other end was led around a drum used to put tension upon the rope. A leather hammock suspended from the cable by a

loop or clue at either end, served as the transporting carriage for both men and animals. A small rope affixed to this hammock, and leading to either shore was used to draw passengers across. Sometimes two tarabitas were used side by side, the cables being inclined in opposite directions.

Turner, in his "History of his Embassy to Thibet" describes an ancient bridge at Bootan in Asia. It was built for the accomodation of a single passenger and communicated between two mountains. The bridge consisted of two parallel ropes made of twisted creepers, encircled by a loop. The traveler sits in the loop between the ropes and draws himself along by hand. A bridge of this type crosses the River Sutlej, British India, a raging torrent in a rocky highland glen. The bridge is called a "jhoola" or rope bridge. The passenger takes his seat in a loop of rope made to slide along the stretched cable, and is hauled over by men on the opposite bank of the river.

Another type of rope suspension bridge is the three-rope foot bridge. It concists of a single tight rope with two smaller ones at higher levels, to form side supports for the traveler. An example of this type is shown in Fig. 1. This bridge crosses the Jhelum River in Northern India. It is interesting on account of the simplicity of

Fig. 1 An Indian Foot Bridge

the floor and the remarkable uniformity of the spreaders, which though of natural growth, are practically the same angle and size throughout the bridge. A similar and almost equally primitive suspension bridge is the one built over the Canadian River in Oklahoma. This bridge, however, as may be seen in the illustration, Fig. 2, has an elaborate floor system as compared with that of the Hindoo structure. The bridge is hung between two trees. It was built by "line walkers" whose duty it was to inspect the main trunk pipe line

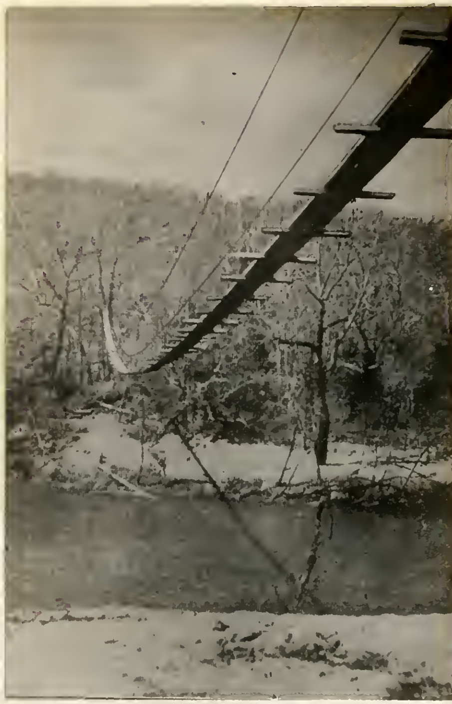

Fig.2 Suspension over the
Canadian River, Oklahoma

of the Gulf Refining Co.

At the discovery of America, bridges resembling the suspension type were found. In the year 1802 Humboldt found a suspension bridge across the River Chambo, in Peru, South America, the ropes being 3 feet thick, made of roots of the Agave Americana. The span was 40 feet. A

similar bridge called the "Penepe" crossed the River Chambo in Quito, South America. The cables were made of plant fibre 4 inches in diameter; were supported on timber end frames and fastened to posts driven into the ground, the road lying on the cables and conforming to their curve. The span was 131 feet. Another bridge in Peru of similar character is said to have had a span of 225 feet and to have been built many years ago. A native bridge at Caucasus had a span of 80 feet. It was a narrow foot path, strong enough for loaded mules. It consisted of two cables made of twisted creepers and fastened to trees on shore.

Rope bridges were much used in times of war. One across the Padus River in Italy, built in 1515 by the Landsknechte, a kind of regular troops, (Germans and Switzers) to transport artillery. In the year 1595 Admiral Coligny built a rope bridge across the Clain, in France, and used it in the siege of Poitiers during the reign of Charles 1X of France. Henry, Prince of Orange used similar bridges in his campaign against Ghent and Bruges in 1631.

Information relating to the early history of bridges in China is very indefinite, but enough is known to prove that suspension bridges were used in that country in very remote times. The first

[illegible] bridge called the "[illegible]" over at the [illegible] River [illegible] in [illegible], South America. The cables were made of plant fibre 4 inches in diameter; were supported on timber end frames and fastened to posts driven into the ground, the road lying on the cables and conforming to their curve. The span was 131 feet. Another bridge of very similar character is said to have had a span of 225 feet and to have been built many years ago. A native bridge at [illegible] had a span of [illegible] feet. It was a narrow foot path, strong enough for loaded mules. It consisted of two cables made of twisted [illegible] and fastened to trees on shore.

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Information relating to the early history of bridges in China is very indefinite, but enough is known to prove that suspension bridges were used in that country in very remote times. The first

one of which any date is given was built in A.D. 65 by order of the Emperor Ming, in the province of Yunnan, as described by Kirchen. This bridge was 330 feet long, with a plank floor resting on chains. A very early bridge crossed the Tchin-Chien River in Thibet with a span of about 140 feet, called the "Bridge of Chuka Castle". The natives had no knowledge of its building and attributed it to fabulous origin. It consisted of a roadway carried by five chains covered with bamboo railing on either side for the security of travelers. A chain bridge found at Bootan by Turner consisted of two chains, 4 feet apart, between which a plank walk 8 inches wide for foot passengers was suspended by roots and creepers, which latter had to be replaced annually. This bridge had a span of 70 feet.

Fig.3 Rope Bridge at Carrick-a-Reede, Ireland

More recent bridges of this type may be found at Carrick-a-Reede, Ireland, as illustrated in Fig.3, and one over Tygert Creek in Carter County, Kentucky Fig.4, with a span of 140 feet, and cables fastened to trees. It has two main cables made of an old

Fig.4 Primitive Suspension Over
Tygert Creek, Kentucky

wire incline-rope. Considerable skill and experience are required for a safe passage. The upper cable shown was originally put in place for a hand rail.

In the year 1734 the army of the Palatinate of Saxony, in Germany, built a chain bridge across the Oder River near Glorywitz, in Prussia. It was used for military purposes. A chain stretched

across between two rocks that command the town of Monstiers in the Department de Basses Alpes is mentioned by M. Navier. It appears however not to be used as a bridge, but rather as an offering to the Virgin to obtain protection for the town. It is interesting to note that the iron is said to have been uninjured by rust. The chain is 656 feet long, made of rods 2 feet $1\frac{1}{2}$ inches long and 3/8 inch in diameter hooked into one another. The time of erection is supposed to have been about the 13th century.

There are no accounts of the existence of iron suspension bridges in Europe before the 18th century. The first European suspension bridge appears to have been built in England about 1741. It crossed the River Tees near High Force two miles from Middleton. The Tees bridge was built for the convenience of miners in the district. Its span was 70 feet and width a little more than 2 feet. The floor lay directly on cables about 60 feet above high water. A hand railing was provided on each side for the protection of the traveler. In 1802 the bridge fell, killing one or two people and was replaced by a similar one known as the Wynch Bridge which was still standing in 1908.

It was believed that the invention of suspension bridges by Sir Samuel Brown, sprung from the sight of a spider's web hanging across the path

of the inventor, observed on a morning's walk, when his mind was occupied with the idea of bridging the Tweed. The artificer of the web, who really guided Sir Samuel Brown, was the American engineer, James Finley, of Fayette County, in the State of Pennsylvania. In the year 1796 Finley built the first regular suspension bridge across Jacobs Creek, on the turnpike between Uniontown and Greensburg, in Pennsylvania. The Principal features of Finley's invention consisted in the application of artificial stone abutments, in the introduction of only two chains, one on each side of the bridge, the links of which were as long as the distances between cross-bearers or joists. He also applied 1/7 of the span for the deflection of the cables, introduced the suspension rod and stirrups and used the same angle as the main chains for the anchor chains to avert the powers acting to overthrow the towers. His specifications read as follows: "To bind and connect the whole that they have the same effect as a platform of one piece, four or more joists will be necessary for the upper tier - to extend from end to end of the bridge; each will consist of more than one piece, and the pieces had best pass each other side by side so that the ends may rest on different joists on the lower tier. The splice will then extend from one joist to another of the lower tier, and must be bolted

together by one bolt at each end of the splice. The planking floor is laid on the upper tier."

These beams served to stiffen the floor or, in other words, to neutralize the moment arising from the loads and wind. From a careful study of Finley's plans we can see, how through misunderstanding and neglect of his well founded directions, many disasters were caused to suspension bridges.

The bridge across Jacobs Creek had a span of 70 feet and was supported by two iron chains, one on each side of the bridge. The links of the chains were as long as the distance between floor joists. The floor was of wood 12½ feet wide suspended from the chains. The cables had a sag of 10 feet or as Finley recommended 1/7 of the span and passed over masonry towers with the same angle of inclination on each side.

Until the year 1801, according to Finley's patent, eight bridges had been built in the United States, and between the years 1801 and 1808, forty others had been erected. The largest of all was the Schuylkill chain bridge of 306 feet span. This bridge crossed the Schuylkill River at Fairmont Park, Philadelphia. It is represented by an old illustration with two spans of 153 feet each. It was the first appearance of a suspension bridge with more than one span. The cables were made of long

iron links from which the floor was hung with rods. It collapsed in the year 1811 under a drove of crowding cattle and was replaced by another suspension bridge which fell on January 17, 1816, under a weight of snow and ice. A third bridge was opened in July 1816 and had a single 408 feet span with a passage way of only 18 inches. This bridge was the work of White and Hazard, who owned and operated a wire mill near by. The cables were made of six 3/8 inch wires. It is noted for being the first wire suspension bridge in any country. The bridge fell the same year under a load of snow and ice, and was replaced by the Colossus, a wooden bridge which was opened in December of 1817.

It is interesting to know the names of some of Finley's first suspension bridges.

The Potomac Bridge, near Washington, had a span of 13o feet, its floor being 15 feet wide. It was supported by two chains of $1\frac{1}{4}$ inch wrought iron bars. The Cumberland Bridge in Maryland had the same span; the Brandywine Bridge, near Wilmington, Delaware, was built with a 145 feet span and a roadway 30 feet wide; and two at Brownsville, Pennsylvania in Fayette County, with spans of

120 feet. The one at Wilmington over the Potomac was washed out by a freshet about 1840 and was replaced by a wooden bridge. A bridge across the Merrimac, 3 miles above Newburyport, in the State of Massachusets, which replaced Timothy Palmer's old wooden one of 1792, was built under the direction of John Templeman, of the District of Columbia. It is one of the most interesting buildings in the history of bridges.

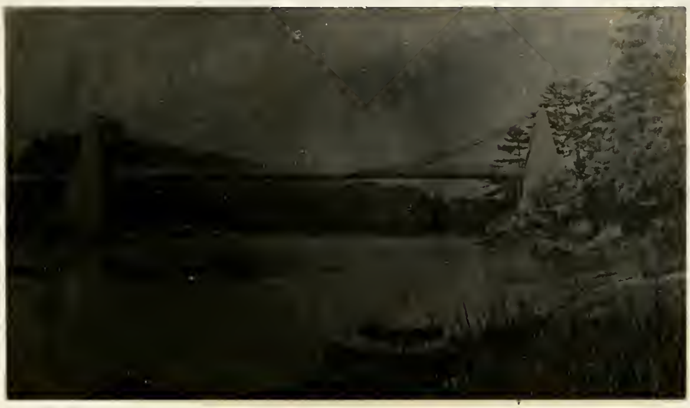

Fig.5 Essex-Merrimac Chain Suspension

The span of this bridge, Fig.5, was 244 feet, the towers were 47 feet long and 37 feet high, and made of good masonry. The two roadways were 15 feet wide, each having two sets of cables containing three chains each or a total

of twelve chains. The chains were made of links 1 inch square and 27 inches long. One chain broke in 1827 under a load of four oxen and a horse. It was repaired and again strengthened in 1900 by adding two new wire cables to one of the roadways. This bridge, known as the Essex-Merrimac suspension bridge, was thrown open to the public in November of 1810, and was closed in the summer of 1909, on the assumption that it was unsafe after a century of use.

Mr. Finley designed two bridges crossing the Lehigh River, one at Northampton, Pennsylvania, in 1811, and another at Allentown in 1815. The bridge at Northampton had a total length of 475 feet, three towers supporting two intermediate and two end spans, double roadways and two foot-walks 6 feet wide. This was the second suspension bridge of more than one span. The Allentown Bridge had two spans of 230 feet, cables of iron bars carrying a roadway 30 feet wide. It was damaged by fire in 1828 and carried away by a flood soon afterwards.

The application of wire for suspension bridges is also an American invention, as the first wire bridge was built before the year 1808, at Philadelphia, over the Schuylkill River, with a span of 408 feet. The existence of the American wire suspension bridge was well known in

of twelve chains. The chains were made of links 1 inch square and 27 inches long. The chain broke in 1807 under a load of four oxen and a horse. It was repaired and again strengthened in 1909 by adding two new wire cables to one of the roadways. This bridge, known as the Chain-Hermitage suspension bridge, was opened to the public in November of 1808, and was closed in the autumn of 1909, on the assumption that it was [illegible] after a century of use.

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Europe a long time before the first regular suspension bridge was built there. Pope's book, which mentioned this type of bridge, was well known in France, and Seguin, as well as the famous French engineer Navier, made use of it. Sir Samuel Brown knew of Finley's important invention in connection with Templeman's improvements as early as 1814. Navier was sent by the French Government to England in 1821 to study and investigate suspension bridges, and two years later he published a book on the subject, which was followed in 1824 by a treatise written by the elder Seguin. Navier used 1/12 and 1/15 of the span as the versed sine of the cable while Finley's bridges had a deflection of only 1/7.

Sir Samuel Brown was the first engineer in England to investigate and develop the suspension bridge. He proposed, in 1811, the use of flat bars or links for cables instead of square and round bars as previously used. During the years 1814 to 1830, although several of his structures collapsed, Mr. Brown greatly improved the design of suspension bridges. The English engineers were the first to propose and apply stays for suspension bridges in connection with cables as well as without them.

Europe a long time before this first European suspension bridge was built there. Pope's book, which mentioned this type of bridge, was well known in France, and Navier, the head of the French Bridge Engineers Society, must have heard of it. The actual knowledge of Finley's important invention in connection with Telford's improvements as early as 1821. Navier was sent by the French Government to England in 1821 to study and investigate suspension bridges, and two years later he published a book on the subject, which was followed in 1826 by a treatise written by Marc Seguin. Navier used 1/12 and 1/15 of the span as the versed sine of the cable while Finley's bridges had a deflection of only 1/7.

Sir Samuel Brown was the first engineer in England to investigate and develop the suspension bridge. He patented, in 1817, the use of flat bars or links for cables instead of square and round bars as previously used. During the years 1818 to 1826, although several of his structures collapsed, Mr. Brown greatly improved the design of suspension bridges. The English engineers were the first to propose and build stays for suspension bridges in connection with cables as well as without them.

The first of these bridges was built by Richard Lees, at Galashiel, over the Galawater in the year 1816, of a span 112 feet and cables of slender wire. The bridge at Kings Meadows, over the Tweed, was built the following year. It was designed by Redpath and Brown with a span of 110 feet, and a 4 feet deck and similar cables. It had iron towers 9 feet high, stays, plank floor and a railing. Another structure at Thirlstone Castle had a span of 125 feet. At Kelso, on the Tweed, a bridge of 300 feet span was built for carriages. The roadway was 18 feet in width. A bridge at Dryburg Abbey over the Tweed, with stays, was 260 feet long. It was built by Messrs. Smith and was very movable, so much so that four persons could shake it so as to break one of the stays. In the year 1818 it was blown down but soon after it was rebuilt according to Finley's system, which provided for strong longitudinal beams, railings, and anchors, like those at the Niagara bridge, to resist the obnoxious motion. The cables were 12 feet apart at the towers and 4 feet apart at the center, the object being to reduce the side motion. This was probably the first use of cradling.

In 1819-20 Mr. Brown designed and built the first large suspension bridge in Great Britain, the Union Bridge over the River Tweed, at Berwick.

The span was 449 feet with a roadway 18 feet wide suspended from twelve cables, six on each side. The cables hung in three tiers above each other with two chains in each tier. They were made of round wrought iron, 2 inches in diameter, 15 feet long united by coupling links, 1 1/8 inches in diameter and 7 inches long. About six months after the completion of the bridge it was blown down by a violent storm. Despite the fact that several of Mr. Brown's structures collapsed, he greatly improved the design of suspension bridges, but neither he nor Mr. Telford used stay cables.

A project for bridging the Menai Straits, between the Islands of Anglesea and Carnarvonshire, in Wales had been considered in England for many years. Between the years 1776 and 1819 several designs had been submitted by Golbourne, Nichols and Telford, but were not accepted. Finally a suspension bridge was decided upon, and actual construction was begun in 1819 under the direction of Thomas Telford, as chief engineer. The bridge, Fig.6, had a central span of 58o feet and two side spans of 28o feet each with four stone arches of 5o feet at one end, and three similar ones at the other end, making a total of 1701 feet. The platform is 30 feet wide divided into 12 feet driveways with a 4 feet walk between them, at an elevation of 120 feet above

low water and suspended from 16 main cables, one set at each side of the roadway. The cables have a versed sine of 43 feet and pass over stone towers founded on rock, the top of the towers

Fig.6 Menai Straits Bridge, England

being 152 feet above high water. Each chain contains five iron bars $\frac{3}{4}$ inch by 1 inch, 10 feet long united by 8 inch by 16 inch links and 3 inch pins. It was badly damaged by a violent wind storm in January 1839, when one-third of the hangar rods were broken and both roadways made impassible, but it was soon afterwards repaired.

Suspension bridges were introduced on the continent about 1820. The first was at Geneva over the Fosse in 1823. This bridge had two equal spans of 132½ feet. The platform was 7½ feet wide and 300 feet long supported by round rod hangars from 4 wire cables, two at each side of the roadway. The upper and lower cables were 1 inch and 1 1/8 inches in diameter respectively. Several other wire suspension bridges were built in France during the same year by the Seguin Brothers of Lyons.

During the same year, Telford designed and started construction of a bridge to cross a deep and rapid Channel in North Wales which adjoins the old Conway Castle, now in partial ruins, at that point. The bridge known as the Conway Bridge is shown in Fig.7. It had a span between the towers of 327 feet and 4 eye bar chains on each side 3½x1inchx9feet long hung above each other but not connected. The chains have a center sag of 22 feet and are anchored back into the solid rock. The bridge continued in use in its original condition for 80 years, but was then found to be insufficient for modern loads and travel. It was strengthened in 1904 by the addition of new anchorages, four new wire cables, two on each side, and new suspension links and stiffening girders 8½ feet deep.

Fig.7 Conway Bridge, North Wales

In 1823 Sir Samuel Brown designed and built the Brighton Chain Pier. The length over all was 1,136 feet, with four spans of 225 feet. The deck was supported by four chains at each side of the roadway. Each chain consisted of links 10 feet long, joined by double couplings and bolts. It had a sag of 18 feet in each span. After being used for 13 years the pier was damaged by the action of heavy waves during a great storm. The total cost of this structure was $150,000.

In 1826-27, when Telford was completing the two suspension bridges at Bangor and Conway, a notable one of several spans was begun under the direction of Thomas Haven, at Newburyport,

Masssachusetts. This bridge crossed the Merrimac River between Newburyport and Salisbury, below Carr Island. It had three river and two shore spans supported on two abutments. The cables were wrought iron links with four groups of three links in each, supported on timber towers 31 feet high, standing on log cribs filled with stone.

Between the years 1824 and 1827, William Tierney Clark designed and erected the Old Hammersmith Bridge across the Thames at London. This bridge had a central span of 400 feet, and two side spans of 147 feet. After 60 years of use it was found to be too light and was rebuilt on the old foundations under the direction of Sir J. Bazalgette. It is ornamental and one of the most attractive objects in London. The erection of the bridge at Vienna, over the Danube Canal, saw the first use of steel for bridge building in any country. It had a span of 334 feet and cables consisting of flat eye-bars of open hearth steel. It was taken down in 1860, and was replaced by another suspension bridge, designed by Schnirch, with a clear span of 225 feet. This was the first and only railroad suspension bridge in Europe. In 1884-5 it was again replaced by an iron arch. The second

structure had two vertical lines of braced chains at each side, 4 feet apart.

During the years 1829-30, two suspension bridges appeared in England; the first one at Montrose having a span of 432 feet and cables of flat wrought iron bars. Sir Samuel Brown designed this bridge and nine years after it was opened, it met the fate of his other bridges at Brighton and Berwick. In 1840 the chains gave way with a load of 7oo men on the floor, causing a considerable loss of life. Rendel reconstructed the bridge and stiffened it with trussing. The second bridge was also designed by Brown and crossed the Tees carrying a railroad from the Durham coal fields into Yorkshire. It had a clear span of 281 feet with stone towers and a cable sag of 28 feet. The deflection was so great that piles were driven under the platform to support it, and in 1841 nothing remained except the chains In 1842 it was replaced, under the direction of Geo. Stephenson, by a cast iron bridge of five spans.

About 1832 James Dredge evolved a new suspension bridge principle with floor rods inclined instead of vertical. He arranged the chains in vertical planes increasing uniformly in sectional area from the center of the span to the towers, combined with a compressive member at the floor level. His bridge across Balloch Ferry, Loch

Lomond, was designed according to this principle. This bridge had a total span of 292 feet and was 200 feet between towers. The chains were made of 13 rods, 7/8 inch in diameter at the towers, decreasing uniformly to a single rod at the center of the span. A bridge of this type, with latticed trusses and battlemented towers, was also designed by Mr. Dredge to cross the River Spey.

In the year 1831 the French engineer Vicat, in his report on the suspension bridges across the River Rhon, described his method for building wire bridges in place, directly on the towers and abutments. The method is as follows:

"The towers and abutments of a suspension bridge being finished, the points of attachment ready to receive the cables, and supposed that a number of double wires of equal lengths, forming circuits, are wound on different reels, these are drawn from one pillar to the other by means of a thin endless rope, like the guide rope of a flying ferry, and moved like the chain of a chain pump."

Mr. Chaley applied this method to the celebrated bridges at Friburg, Switzerland. The first and smaller bridge crossed the Saone Valley with a span of 195½ feet. The cables were anchored into rock banks. The larger structure Fig.8, had a single span of 870 feet between

towers. The cables had a versed sine of 63 feet, and carried a floor 810 feet long at an elevation of 167 feet above the Saone Valley. It originally had four iron wire cables, two on each side of the roadway, each cable containing 1056 wires.

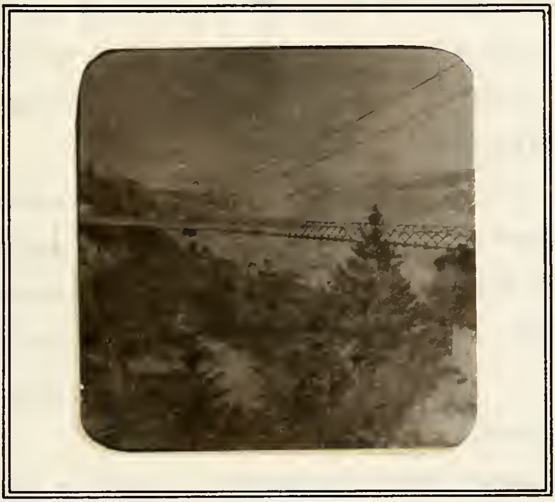

Fig.8 Friburg Suspension, Switzerland

The platform was 2 feet higher at the center than at the ends. The roadway was 15 feet wide with 2 feet 3inch sidewalks and wooden floor beams hung from the cables with wire suspenders, making a total width of 21 feet. The piers were of solid masonry 20 feet thick at the road level and 66 feet above it, with Doric porticos. The cables were securely anchored into the rock. It was severely tested by a detachment of 15 cannon, 50 horses and 300 people passing over it, deflect-

ing under the combined load about 39 inches. In 1880 it was reinforced by adding one more cable on each side. Mr Chaley also erected, according to the same method, the bridge "de la Carite", across the River Laire, a suspension bridge in Paris, another at Percy, in the Jura Mountains, and the bridges Comery, across the Indre, and of Beaumont, across the Sarthe, in France.

The first use of the triangular bracing between double chain cables was at the erection of the Weser suspension bridge near Hamelu, by Wendelstadt. It was removed in 1899 to Hessich, Oldendorf, and the Weser Bridge was rebuilt as a cantilever.

A very picturesque suspension bridge is that at Cubzac, across the River Dordagne, in France. This bridge has five continuous spans of 363 feet, supported on cast iron towers 82 feet high. Iron towers also were used at the chain bridge at Searing, in Belgium, over the Mass, and at the chain bridge at Muehlheim (1850) on the Ruhr, in Prussia. Since the accident of the wire bridge at Angers, in France, in the year 1850, and the failure of the bridge at Broughton, near Manchester in 1831 under a march of sixty soldiers, many of the wire bridges in Paris have been replaced by truss and arch structures, and a law was introduced directing tests of wire bridges

from time to time. The failure of Sam. Brown's suspension bridges at Berwick, Brighton, Montrose and Durnham were a serious check to building in England.

Seguin was the first man in Europe to build a suspension bridge for railway purposes, and with full success. His bridge over the Saone had two spans of 137½ feet each. There were three cables at each side of the bridge with a sag of 16 2/3 feet. It was stiffened with girders about 8 1/3 feet high, composed of wooden beams 9 x 2½ inches, and chords of 13 x 6½ inches, connected vertically with the longitudinal beams of the floor. After 4 years of use, it was replaced by a stone bridge.

The older of two chain bridges over the Danube at Budapest was the work of W. Tierney Clark. It had a total waterway of 1,250 feet made up of a central span of 666 feet and two side spans of 298 feet each. The stone towers were very artistic in outline and detail, standing at a height of 200 feet above the foundations. There are four flat eye-bar chains with a sag of 47 feet. It was severely tested, when for two days the Hungarian army retreated followed by 30,000 Austrians, both armies having cannon, heavy ammunition and supply wagons. Clark died before the bridge was completed. His

from time to time. The failure of Gen. Green's experimental [illegible], [illegible], structures and [illegible] were a serious check to [illegible] in England.

[illegible] was the first man in [illegible] to build a suspension bridge for military purposes, and with full success. His bridge over the [illegible] had two spans of 157½ feet each. There were three cables at each side of the bridge with a [illegible] of 16 2/3 feet. It was stiffened with girders about 8 1/3 feet high, composed of wooden beams 3 x [illegible] inches, and chords of 12 x 12 inches, connected vertically with the longitudinal beams of the floor. After 4 years of use, it was replaced by a stone bridge.

The older of the chain bridges over the [illegible] was the work of [illegible] Tierney Clark. It had a total waterway of 1,250 feet made up of a central span of 666 feet and two side spans of 292 feet each. The stone towers were very artistic in outline and detail, extending to a height of 200 feet above the foundations. There are four flat eye-bar chains with a dip of 47 feet. It was severely tested, when for two days the [illegible] were transported [illegible], [illegible], [illegible], heavy ammunition and supply trains. Clark died before the bridge was completed. His

brother Adam took up the work and finished the bridge.

In 1840 Col. Charles Ellet made an offer to bridge the Ohio River at Cincinnati with a 1,400 foot suspension bridge, 112 feet above the water. He made a similar proposal in 1849. In 1846 John Roebling reported on a proposed brodge at the site, with a span of 1,057 feet as finally built. The first plan had a tower in the middle which was objectionable and was not accepted. Erection was begun in 1856 but was delayed by the panic of 1857, and the war further delayed it until 1863, after which time construction was continued until its completion in 1867. This was the longest suspension bridge previous to the one at Brooklyn. It had two wire cables 12½ inches in diameter with a versed sine of 90 feet, numerous stay cables, and stiffening trusses 10 feet deep. The bridge was strengthened in 1897-8 by the addition of two new steel cables, 10½ inches in diameter and by increasing the width of the road to 30 feet with walks of 9 feet.

Other wire suspension bridges prior to 1842 were those at Suresne and Lorient, in France. The Suresne bridge had a center span of 203 feet, sag ratio 1/10 with two side spans of 139 feet

each. It had ornamental stone towers, and a roadway 22 feet wide and 500 feet long. The floor was suspended from cables of thin flat iron at 35 feet above low water. These cables are stiffer though not so strong as wire.

A double chain bridge over the Moldau, at Prague, was built about this time (1845). It had center and end spans of 433 and 109 feet respectively, and stone towers. This bridge was designed by the Austrian engineer Schnirch. The Douro River suspension bridge at Oporto, had a span of 558 feet. There were eight cables, four on each side with a sag of 45 feet, anchored at one end into the cliff, and into horizontal foundations at the other end. The towers were of stone, 59 feet high. It was built under the direction of M. Stanislaus Bigot. The Gotteron bridge (1840) had a span of 640 feet at a great height with ends at different elevations.

A wire bridge was erected across the Schuylkill River at Fairmount Park, Philadelphia, in 1842 and replaced the Colossus which burned in 1839. The site had been occupied from 1809 to 1816 by two other suspension bridges which collapsed under successive loads. The new bridge was designed by Charles Ellet, who 10 years before had proposed the span of 1,000 feet at Washington. Ellet's suspension bridge

had a span of 358 feet supported by wire cables, five at each side. It had a clear width of 25 feet and remained in use until 1874, when it was replaced by the present double deck truss bridge.

The Hungerford foot bridge over the Thames at Charing Cross (1842-45) was the work of Isambard K. Brunel. It was the longest chain suspension, having a central span of 676 feet, versed sine of 50 feet and two side spans of 329 feet. There were four main chains tow on each side, composed of 7 x 1 inch flat links, 24 feet long, connected with 4 5/8 inch pins. The roadway was 14 feet wide and the wooden beams were suspended from the chains with rods hung from small metal levers, the two ends of which were supported separately from each chain, to load the cables uniformly. Each chain was connected to the saddles resting on iron rollers over brick towers, allowing a movement of 18 inches in either direction from the center line. The bridge was removed to make room for the new Charing Cross railroad bridge but was re-erected at Clifton, England in 1863.

The bridge over the Ohio River, at Wheeling (1846-49) had a central span of 1010 feet and was the longest span of any kind in existence. It was the work of Col. Ellet and was somewhat

similar to his proposed bridge over the Potomac, at Washington 14 years before. The bridge was 24 feet wide and the platform was suspended 97 feet above low water. It had six separate cables on each side of the road containing 6,600 wires. In 1854 it was damaged by a tornado when the floor was turned over and all the cables but two were broken in succession at the anchorages. It was repaired by Roebling, who united the separate strands into solid cables, and placed them farther apart at the towers than at the center. It was again rebuilt in 1862. The failure and repairing of this bridge brought the systems of Roebling and Ellet into contrast. Mr. Ellet used separate strands side by side, with iron bars fastened across them, from which the suspenders hung, while Roebling used wire cables in cylindrical form, enclosed and wrapped with light wire to protect them from the weather.

In 1844 the Hon. William Hamilton Merrit, of St. Catherines, Ontario, suggested the plan of spanning the Niagara Gorge with a suspension bridge, and in 1846 through his efforts, charters were obtained from the State of New York and the Canadian Government for the construction of the first bridge across the gorge. In 1847 the bridge companies made a contract with Charles Ellet to construct a bridge on the site occupied

by the present bridge. Mr. Ellet first threw across the gorge a cable of thirty-six No. 9 wires, on which a light iron carriage was run for about a year, and used for the purpose of subsequent work and for passenger service. From this he developed the earliest bridge, $7\frac{1}{2}$ feet wide, at a cost of $35,000, which was strengthened the same year to carry material and supplies for the larger bridge, which was to be built. A kite was used to take the first cord across the gorge. This in turn drawing over a larger one which pulled over a rope, to which the first wire cable was attached. Mr. Ellet's connection with the work ceased on the completion of this bridge, and he had no hand in planning the railway bridge as finally built. On completion of the heavier bridge, Ellet's light foot bridge was removed. In March, 1848, Mr. Ellet erected a basket ferry over the Niagara two miles below the falls. A toll of $1.00 per passenger was charged. The car basket was made of light iron work with seats on each side, and was large enough to accomodate four passengers. It was hung by a trolley from a single wire cable, and was drawn back and forth between opposite banks.

by the present bridge. Mr. Ellet first built across the gorge a cable of thirty-six No. 9 wires, on which a light iron carriage was run for about a year, and used for the purpose of subsequent work and for passenger service. From this he developed the auxiliary bridge, 7½ feet wide, at a cost of $25,000, which was strengthened the same year to carry material and supplies for the larger bridge, which was to be built. A kite was used to take the first cord across the gorge. This in turn drawing over a larger one which pulled over a rope, to which the first wire cable was attached. Mr. Ellet's connection with the work ceased at the completion of this bridge, and he had no hand in planning the railway bridge as finally built. On completion of the [illegible] bridge, Ellet's light foot bridge was removed. In August, 1848, Mr. Ellet started a basket ferry over the Niagara two miles below the Falls. A toll of $1.00 per passenger was charged. The car basket was made of light iron strap- with seats on each side, and was large enough to accommodate four passengers. It was drawn by a trolley rope [illegible], and was drawn back and forth between opposite banks.

Two important bridges at Pittsburg (1844-47) were the work of John A Roebling, one of them being a suspension aqueduct over the Allegheny River, and the other a highway bridge across the Monongahela River. The former had seven spans of 162 feet with two 7 inch wire cables supporting a wooden flume. The project met with opposition but was completed in 1845 and remained in use until the canal was abandoned in 1861, when the bridge was removed. Roebling was the first to use suspension aqueducts and previous to 1848 he built four others with openings of 115 to 170 feet. The other bridge at Pittsburg was the Smithfield Street Bridge, which connected Central Pittsburg with South Pittsburg. It was built on the abutments and piers of an old wooden bridge, the superstructure of which had burnt down in 1845. The cast iron towers had the appearance of square truncated pyramids, 7½ feet square at the base and 4 feet at the top, and were 16 feet high. The roadway was 20 feet wide, having two lines of car tracks. The sidewalks were on the outside of the cables, and were 5 feet wide. A wooden continuous Howe truss 5 feet high served as a hand rail as well as a stiffening truss.

Two important bridges in Pittsburgh (1844-47) were the work of John A. Roebling, one of them being a suspension aqueduct over the Allegheny River, and the other a highway bridge across the Monongahela River. The former had seven spans of 160 feet with two 7 inch wire cables supporting a wooden flume. The project met with opposition but was completed in 1845 and remained in use until the canal was abandoned in 1861, when the bridge was removed. Roebling was the first to use suspension aqueducts and previous to 1848 he built four others with openings of 130 to 170 feet. The other bridge in Pittsburg was the Smithfield Street bridge, which connected Central Pittsburg with South Pittsburg. It was built on the abutments and piers of an old wooden bridge the superstructure of which had burnt down in 1845. The cast iron towers had the appearance of square truncated pyramids, 7½ feet square at the base and 5 feet at the top, and were 16 feet high. The roadway was 22 feet wide, having two lines of car tracks. The sidewalks were on the outside of the trusses, and were 5 feet wide. Wooden stiffening trusses [illegible] which served as a hand rail as well as a stiffening truss.

The cables were $4\frac{1}{2}$ inches in diameter, each containing 750 wires of NO. 10 Birmingham gauge wrapped with No. 14 annealed wire. It was completed in 1847 and was in service for 35 years, carrying the heaviest traffic. At that time the bridge had become very shaky and loose; its continuous swaying and creaking had created anxiety in the public mind, and soon after it was removed. A new bridge was decided upon in the summer of 1880, and a contract was entered into to erect one having two channel spans of 180 feet each. A change of management in the bridge company caused the contract to be nullified, and another plan was accepted, which provided for a widening of the bridge by adding another roadway or track should this ever become necessary.

About 1848 a suspension bridge was erected at Roche-Bernard, France, over the Velaine with a span of 650 feet. The platform was suspended from four wire cables at an elevation of 110 feet above water. The cables had a sag of 50 feet. In October 1852 the bridge was wrecked by a gale and in its restoration counter cables were added. The ends of the cables were not loaded and had the same angle of inclination on each side of the towers. It was similar to the bridge at Lorient.

In 1850 construction was started on a suspension bridge over the Niagara gorge at Lewiston, two miles below the falls. At the time of its constbruction, it had the distinction of having the longest clear span of any bridge in the world. It was built under the direction of Captain Edward W. Serrel, and had a span of 1,042 feet with a platform 21 feet wide. The versed sine of the cables was 87 feet. On Feb. 1, 1864, the floor of the structure was blown out

Fig.9 Suspension Bridge over Niagara River at Lewiston N.Y., and Queenston, Ont., 1899

by a hurricane after the guy cables had been temporarily removed. It was not repaired or rebuilt until 1899, when a new one to carry a highway and one line of electric cars was erected

under the direction of Mr. L. L. Buck. The new bridge, (Fig.9), has a span from tower to tower of 1,040 feet. There are four cables each composed of fourteen $2\frac{1}{2}$ inch galvanized cast steel wire ropes which pass over stone towers and support a roadway 25 feet wide. The anchorages are drilled into solid rock.

Other interesting suspension bridges in Canada were those at St. John, New Brunswick, and at Montmorency Falls, Quebec. The bridge over the Reversible Falls at St. John, was designed by Serrell and had a span of 628 feet. The roadway was 20 feet 9 inches wide, suspended from ten cables, five on each side, hanging side by side and parallel. Each cable was composed of 290 straight, parallel No.9 wires, forming strands $2\frac{3}{4}$ inches in diameter. After being wrapped with close No.12 wire, the strands were 3 inches in diameter. The towers were 52 feet high above the floor and measured 15 feet square at the base and 5 feet 8 inches at the top. It was rebuilt in 1857, and after years of service the bridge was taken down in the fall of 1915. It is one of the monuments of early bridge construction in America. The Montmorency Falls Bridge was located just below the falls adjoining the residence of the Duke of Kent. It collapsed

some years ago carrying a wagon and its driver into the cataract 250 feet below. Only the stone towers now remain to mark the site of this early bridge.

One of the first to propose open web, deep stiffening trusses braced together transversely for suspension bridges, was John C. Trautwine, who in 1851 designed a bridge to cross the Delaware River at Market Street, Philadelphia. The design called for four river spans of 1,000 feet each and two end spans of 5oo feet each, wire cables, and trusses 20 feet deep. 18 months later, John A. Roebling suggested a similar arrangement for a railroad bridge over the Niagara River. Lattice stiffening trusses 6 feet deep also were used on a railroad suspension bridge over the Kentucky River at Frankfort, Kentucky, which existed in 1852. It had spans of 100, 261 and 200 feet, no stays, and the floor was supported with rods 3 feet apart. The Niagara suspension bridge, completed in 1855 by Roebling, marks an epoch in the history of this system, it being the first suspension structure built for heavy railroad traffic. The span between towers was 821 feet and the width 15 feet. There were four cables, each 10½ inches in diameter made of seven twisted strands of wire.

It had two decks, the upper deck was for railroad and the lower deck for highway traffic. The upper deck was separated from the road below by flooring. The $10\frac{1}{4}$ inch cables contained 520 wires each or a total of 3,640 wires. The wires of Mr. Ellet's old foot bridge were incorporated with the others. This bridge was successfully

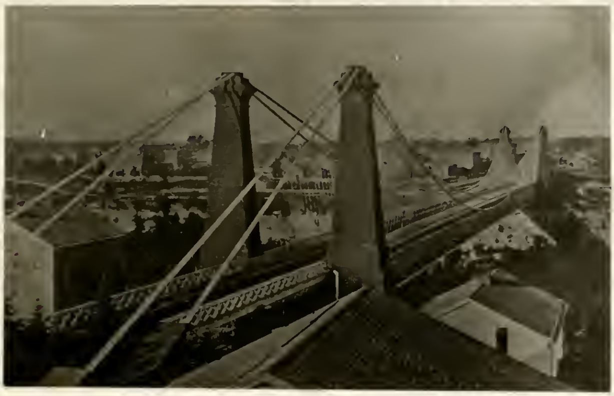

Fig.10 Roebling's Suspension Bridge over Niagara Falls, N.Y., 1868

used for 42 years. As first erected, the bridge, Fig.10, had wooden trusses and towers of stone. It was completed in 1868 and in 1880 the wooden trusses were taken out and replaced by iron ones. The stone towers were changed to towers of steel in 1887 and the bridge was finally completed on

Jan. 12, 1888. Just a year later a violent wind storm broke one of the principal storm stays and the entire suspended structure was carried away and fell on the banks ind into the river. It was rebuilt, and on May 7, 1899 again opened to traffic. In 1897 the bridge was taken down, giving way to the steel arch erected by L. L. Buck. The history of railroad suspension bridges had not been satisfactory, for all have lacked stiffness and rigidity, and those at Niagara, Frankfort, Vienna and Durham over the Tees, have been removed.

The bridge over the Elk River at Lovell Street, Charleston, West Virginia, dates from 1851-52, and was designed by W. O. Buchanan. The distance between tower centers was 478 feet and the floor, 17 feet wide, was on a grade, being 7 feet higher at one end than at the other. The towers were 30 feet high above the floor and supported two 3¼ inch wire cables on each side. It was twice disabled by retreating armies during the Civil War and the last time was completely wrecked. The bridge was privately owned until 1886, but soon after being transfered to the city it was reported as unsafe and failed under a load of 4 inches of ice and snow, killing two people and seven horses, and seriously injuring

Jan. 13, 1886. Just a year later a steamer [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] there [illegible] the entire suspended structure was carried away and fell on the rocks and into the river. It was rebuilt, and on Sept. 7, 1886 again opened to traffic. In 1897 this bridge was taken down, giving way to the steel one erected by [illegible]. The history of [illegible] suspension bridges has not been satisfactory, for all [illegible] lacked stiffness and rigidity, and those at [illegible], [illegible], [illegible] the [illegible] over the [illegible], have been removed.

The bridge over the Elk River at Lovell street, Charleston, West Virginia, dates from 1851-52, and was designed by [illegible]. The distance between tower centers was 478 feet and the floor, 17 feet wide, [illegible] [illegible] [illegible] [illegible] 7 feet [illegible] [illegible] the [illegible] [illegible] of the [illegible]. The towers were 30 feet high above the floor and supported two [illegible] cables on each side. It was [illegible] [illegible] [illegible] [illegible] the [illegible] [illegible] the last time was completely [illegible]. The bridge was [illegible] [illegible] until 1904, [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] it was [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible], killing two people and [illegible] [illegible], and seriously injuring

several other persons. Two similar suspension bridges at Morgantown, West Virginia (1855), and over the Gauley River at Fairmont, West Virginia, were used during the Civil War. The Morgantown Bridge had a span of 608 feet supported by two cables on each side of the roadway made of parallel wires bound at intervals only. One cable broke about 25 years ago under a heavy load of snow, but fortunately the other cables held until repairs could be made, so that the failure was not complete.

About 1854, Thomas Page designed and built the Victoria suspension bridge at Chelsea, which forms a connection between Pimlico, Belgravia, and Chelsea on one side of the river, and Battersea Park and the surrounding country on the other. The length of the Chelsea bridge is 704 feet face to face of abutments, consisting of a center opening of 333 feet with two side openings of 166 feet 6 inches each. The roadway had a width of 47 feet, is cambered 18 inches, and is 24 feet 6 inches above high water. The towers which support the chains are cast iron columnar framing, strongly braced and 57 feet high above high water. There are four flat eye-bar chains, two on either side, at a distance apart of 32 feet, and consisting of links of

seven and eight bars alternately. It is stiffened with lattice girders 6 feet deep.

In January of 1855 the first suspension bridge (Fig.11) to span the Mississippi River was opened to traffic at Minneapolis, connecting the west bank of the river with Nicollet Island. It had a span of 620 feet and was built under the direction of Thomas M. Griffith. There were

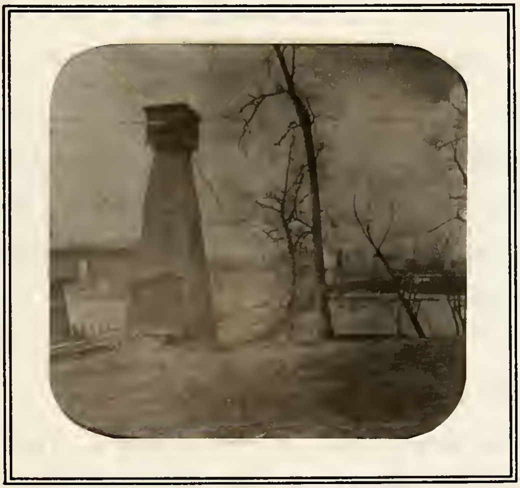

Fig.11 Suspension Bridge over the Mississippi River at Minneapolis, 1855

four cables containing 2000 strands of No. 10 wire supported on wooden towers composed of 16 wooden posts of 12 x 12 inch white pine timber with a base 14 feet square. The cables were cradled and had a sag of 47 feet. After 20 years of service it was found to be insufficient

for increased traffic and in 1876 was replaced by a new and heavier one of 675 foot span. The new bridge had two main cables 10 inches in diameter containing 3,648 strands of No.9 wire, and two side walks cables 4 inches in diameter containing 450 strands of the same size wire. The cables had a sag of 58 feet and were cradled 6 feet. It had two lines of wooden Howe stiffening trusses, 7 feet deep, at each side of the roadway and two outer ones, 6 feet deep. Four stay cables were used in each quarter. The masonry towers were 111 feet high and 35 feet apart on centers. In 1888 a new steel arch was erected beside the suspension bridge and in 1890, when the arch was completed, the suspension bridge was removed at a cost of $3000.

A suspension bridge built in 1855 at Grand Falls crossed the St. John River in New Brunswick about 210 miles above the Reversible Falls Bridge. The span between towers was 209 feet 9 inches. The roadway was 16 feet in clear width and supported by two straight-wire wire wrapped cables of 5½ inches finished diameter resting on stone towers 21 feet 4½ inches high above the floor and anchored 125 feet back. The cables were cradled slightly. It was removed in 1915.

The Clifton Bridge (Fig.12) over the Avon at Bristol, England, is of interest because of its engineering features and pituresque location. Construction was begun and the towers built in 1829-30, but stopped and not resumed until 1840 when Brunel took up the work. It was

Fig.12 Clifton Bridge over the Avon at Bristol, England

not continued, however, until the old Hungerford Bridge at Charing Cross, London, was removed and parts transported to Bristol to be used in the erection of the Clifton Bridge. It was completed in 1864 by Messrs. Barlow and Hawkshaw at a cost of $500,000. The bridge was carried by six chains, three on each side. The chains were composed

In 1857 Roebling started construction on a suspension bridge to carry the Cincinnati Southern Railroad over the Kentucky River at an elevation of 275 feet above the water on the site of the present three span cantilever structure. The span of the cables was 1,230 feet, but after the towers were completed, building was discontinued owing to the failure of the company. Shortly after Roebling built another suspension bridge over the Allegheny River at Pittsburg which replaced an old wooden one of 1818. There were two river and two shore spans of 344 feet and 171 feet respectively. The deck, 40 feet wide including two 10 foot walks, was supported by four cables, two 7 inches and two 4 inches in diameter. The sag of the cables was 30 feet. It had cast iron towers 45 feet high.

In strong contrast with the Chelsea bridge is the three span bridge at Lambeth. It has a total width of 32 feet and stands on cylindrical piers. The cables are fixed at the top, causing a pull on them from uneven loading of adjoining spans. Mr . Barlow proposed to prevent deflection of the loaded spans by fixing the chains rigidly to the towers and designing them as cantilevers to resist the tension from the chains.

of flat eye-bars and supported a platform 31 feet wide, 252 feet above high water. It had a span of 702 feet center to center of towers, and was the longest span with flat eye-bars in Europe.

While the Clifton Bridge was under construction, two fine suspension bridges appeared in Vienna over the Danube (1860-64). The first one (1860) was the rebuilding of the old railroad suspension of 1828 which had been in service for 32 years. The new bridge had a clear span of 255 feet and the cables were double lines of braced chains 4 feet apart. It continued in use for 25 years when it was replaced by the present arch. The second structure was the Aspen Bridge over the same river at Vienna. It had a clear span of 200 feet and braced chains similar to the former.

Shortly after Roebling had completed his 1057 foot span across the Ohio River at Cincinnati, he made a report on bridging the North (hudson) River at New York, and declared that an iron suspension of 3000 feet would be practicable. A year later he prepared elaborate designs which were a combination of arch and suspension, with stiffening trusses and stay cables for a proposed three span bridge over the Mississippi River at St. Louis, and published a

book explaining and illustrating his design. Mr. Eads' famous arch bridge was accepted instead. In 1867 Samuel Keefer, civil engineer of Ottowa began construction on the Niagara-Clifton suspension bridge located a short distance below the falls. It had a span of 1260 feet between centers of wooden towers. The iron wire cables were imported from England, and supported a floor 190 feet above water. Cradling of the cables was used, the cables being 42 feet apart at the towers and only 12 feet apart at the middle of the bridge. It was stiffened with trusses 6½ feet deep and twelve wire stays from each tower to the floor. Side guys anchoring the bridge to the shore were also used. It was widened in 1888 to 17 feet and on January 5, 1889, was blown down, but was replaced in four months by a new structure with steel wire cables, steel towers and stiffening trusses. On May 7, 1889 it was reopened to travel. Ten years later the whole bridge was replaced with an 840 foot steel arch.

About a year after the Niagara-Clifton bridge was begun, Rowland M. Ordish developed a new form of suspension bridge which was partly a modification of that devised by James Dredge in 1832. He used sloping rods running directly from the panel points of the floor system to the

top of the towers, the direct tension members being supported and held in position by catenary cables between the towers. They had no purpose other than to sustain the weight of the direct tension bars. He built several bridges after 1868 at Prague, London and Singapore. The Franz Joseph Bridge over the Moldau at Prague had a center span of 480 feet and two side spans of 156 feet. It had twelve main and two auxilliary chains with a sag of 60 feet supporting a platform 32 feet wide. In 1898 the straight bars were replaced by wire ropes when the bridge was otherwise strengthened. The Albert Bridge over the Thames, designed by Ordish, had a center span of 400 feet and two side spans of 155 feet. Construction was begun in 1863 and finished in 1873. Another bridge according to the Ordish plan was built at Singapore by Mr. Ordish and Col. G. Collyer. It has a span of 200 feet, a roadway 21 feet wide and two side walks with wooden floor. The platform had a total width of 31 feet. In 1869 Ordish erected a foot bridge over the Moldau at Prague between the old stone bridge and the new suspension bridge. He used only one tower in the middle of the river, believing that it would offer less obstruction than two piers, as ordinarily used. The bridge

top of the towers, the direct passage however being supported and made as possible by catenary cables between the towers. They had no [illegible] [illegible] to [illegible] the weight of the direct tension bars. He built several bridges after 1827 in France, London and elsewhere. The [illegible] bridge over the [illegible] France had a center span of 450 feet and two side spans of 180 feet. It has twelve main and two auxiliary chains with a sag of 40 feet supporting a platform 40 feet wide. In 18[illegible] the straight bars were replaced by wire ropes [illegible] and otherwise strengthened. The Albert Bridge over the Thames, designed by Ordish, has a center span of 400 feet and two side spans of 160 feet. Construction was begun in 1868 and finished in 1873. Another bridge [illegible] in the Ordish plan was built at [illegible] by Mr. Ordish and Mr. [illegible]. It has a span of 280 feet, a roadway 21 feet wide and two [illegible] walks with [illegible]. The [illegible] width of 41 feet. In 1858 Ordish erected a long bridge over the Moldau at Prague between the old stone bridge and the old suspension bridge. He used only one tower in the middle of the river, believing that it would be [illegible] than two piers, as generally used. This bridge

has a clear distance between shore abutments of 629 feet and a clear width of 11 feet. Chains made of steel links $4\frac{1}{2}$ x 1 inch, 21 feet long with heads and $3\frac{1}{2}$ inch pins support the floor.

Two new suspension bridges in Europe about this time were those at Frankfort over the Main and the Angarten Bridge at Vienna. The Frankfort Bridge (Fig.13) crossed the Main between

Fig.13 Frankfort Bridge over the Main, Germany,

Frankfort and Sachenhausen and was designed by Schnirch in 1869. It had stiff riveted members having part cantilever action. The Angarten Bridge at Vienna had a span of 202 feet. It was built on the Fives-Lille system and is an interesting work and highly ornamental.

Between the years 1870-71 two new suspension bridges were erected in the United States, each with a span of 470 feet. The first was across the Brozos River at Waco, Texas. The bridge was designed by Thomas Griffith, engineer of the first bridge across the Mississippi. The second bridge crossed the Allegheny in Warren County, Pennsylvania.

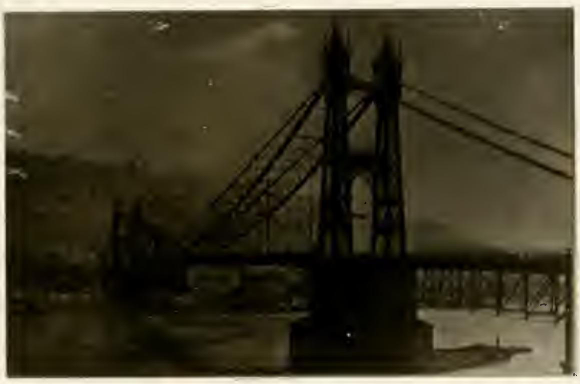

Fig.14 Point Bridge over Monongahela River, Pittsburg, Pennsylvania

In 1876 construction was begun on a very interesting bridge in America. It is of the type commonly known as the stiffened suspension bridge, but in reality it is an inverted arch. The bridge, known as the Point Bridge, Fig.14

Between the years 1870-71 two new suspension bridges were erected in the United States, each with a span of 470 feet. The first was across the Brazos River at Waco, Texas. The bridge was designed by Thomas Griffith, engineer of the first bridge across the Mississippi. The second bridge spanned the Allegheny in Warren County, Pennsylvania.

Fig.46 Point Bridge over Monongahela River, Pittsburgh, Pennsylvania

In 1874 construction was begun on a very interesting bridge in America. It is of the type commonly known as the stiffened suspension bridge, but in reality it is an inverted arch. The bridge, known as the Point Bridge, Fig.46,

is located at Pittsburg, and was designed by Edward Hemberle. It has a center span of 8oo feet and two side spans of 145 feet each, making a total length of 1250 feet. The roadway is 20 feet wide and walks 7 feet wide, and is suspended at a clear height of 80 feet above water. The river piers are of stone and the towers of iron, 110 feet high. The 8 inch eye-bar chains have stiffening trusses above the chains in the form of segmental chords. It is the longest span with flat eye-bars in America, and was repaired in 1906 at a cost of $92,000. Another suspension over the Allegheny at Oil City was built the same year and had a span of 500 feet supported by two cables. It was rebuilt in 1884 and again in 1905.

A very unusual failure of a bridge at Franklin, Pennsylvania, was caused by fire in an adjoining building. The lead which secured the cables into their sockets was melted, which allowed them to pull out and to precipitate the bridge into the river. The Mill Street suspension bridge at Watertow, New York, had a span of 175 feet and a platform 18 feet wide. The platform was supported by vertical rods hung from four main cables. Each cable was made of twisted iron wire rope 2 inches in diameter and had a sag

of $12\frac{1}{2}$ feet. Stiffening trusses were not used in this bridge. It was replaced in 1898 by a steel arch.

A bridge of very interesting and unusual features carries a high road across the River Allier at St. Ilpize, in France. It has a central opening of 223 2/3 feet between cast iron columns having supports for the cables. The two side spans are $49\frac{1}{2}$ feet between columns and abutments. The bridge is suspended 85 1/3 feet above low water level of the Allier at the center. The cables are of twisted iron wire constructed of three elementary cables containing seven strands formed of nineteen No. 18 wires each. These three cables are fastened into a single triangular bundle.

A suspension foot bridge at Iverness over the River Ness has a center and end spans of 173 and 50 feet respectively, supported on steel towers founded on cast iron piers filled with concrete. The roadway is 6 feet wide and is suspended from two wire rope cables, 6 inches in circumference, by means of 5/8 inch rods. Steel latticed stiffening trusses, 4 feet 3 inches deep, were used.

The Teesta Bridge, built in 1879, is situated on a road between Darjeeling and the

Thibet frontier. It has a span of 300 feet with a roadway 6 feet wide. The roadway is suspended from cables of soft steel wire, 2 inches in diameter. Each cable has four strands of wire. The cables are placed side by side and bound together by cast iron saddles fixed 5 feet apart. The versed sine of the curve is 24 feet and the distance between cables at the center of the bridge is 8 feet.

The Lamothe Bridge, similar to the Ilpize Bridge of 1879, crossed the Allier near the town of Brionde. It had a single span of 377 feet between abutments. The roadway was 18 feet above low water, had a width of 18 feet and cambered 2 feet 2 inches. The carriage was 13½ feet wide and the foot walks, one on each side, were 2¼ feet wide. The cables were constructed of twisted iron wire, consisting of seven strands of nineteen No. 21 wires each. There were five suspension cables on each side of the bridge hanging side by side, and twelve anchor cables. The roadway was hung from the cables by strands of 52 No. 18 wires. A similar bridge was built in 1888 to cross the Saone at Lyons with a total length of 397 feet.

In 1884 the Seventh Street Bridge over the Allegheny River, at Pittsburg, was erected from designs by Gustav Lindenthal. It had three towers with two river spans of 330 feet and two shore spans of 165 feet each with a 90 foot truss over the railroad tracks. The suspension chords were composed of two lines of eye-bars with diagonals between them. Its width is 42 feet and the total length is 1,080 feet, both chains being in tension from uniform loads. In the same year a light suspension bridge was built over the Elk River at Charleston, West Virginia, with a span of 273 feet, adjoining the one which collapsed in 1904. It had twisted wire cables, back stays, lattice trusses and iron towers on high stone piers. A few years later after it was completed, one anchor block moved slightly forward, allowing the tower to slope towardsthe river, but it was repaired by William Hildenbrand, who added new anchor masonry. For several years it carried a single line of track for light street car travel, but this was discontinued in December 1904, when the adjoining bridge fell.

On September 15, 1886 as a squadron of Uhlans was crossing the suspension bridge over the Ostrawitza at Mährisch-Ostrau, the structure gave way so suddenly that the whole troop was pre-

In 1884 the Seventh Street bridge over the Allegheny River, at Pittsburg, was completed from designs by Gustav Lindenthal. It has three towers with two river spans of 330 feet and two shore spans of 165 feet each with a 90 foot truss over the railroad tracks. The suspension system is composed of two lines of eye-bars with diagonals between them. Its width is 42 feet and the total length is 1,030 feet, both chains being in tension from uniform loads. In the same year a light suspension bridge was built over the Elk River at Charleston, West Virginia, with a span of 570 feet, adjoining one which collapsed in 1904. It had twisted wire cables, back stays, lattice trusses and iron towers on high stone piers. A few years later after it was completed, one anchor block moved slightly forward, allowing the towers to slope toward the river, but it was repaired by William Hildenbrand, the ... was another company. For several years it carried a single line of narrow gage light street car travel, but this was discontinued in December 1904, when the adjoining bridge fell.

On September 1?, 1905 at a [illegible] of [illegible] the suspension bridge over the [illegible] - [illegible], the [illegible] gave way so suddenly that [illegible] progress [illegible]-

cipitated into the river among the ruins, six men being killed instantly. The length of the bridge was 310 feet 10 inches with a central span of 216 feet 6 inches and a width of 33 feet 3 inches. The towers were 16 feet high and supported chains of sectional area 24.4 sq. inches.

In 1889-91 Carl Gayler designed and erected the Grand Avenue suspension bridge at St. Louis. It carries the street over the railroad yards in three spans. In designing this bridge a special effort was made to secure a structure with a pleasing architectural effect, as well as one having the necessary strength and stiffness. To what extent the designer was sucessful in this respect may be judged from this view (Fig.15) and from a large end view as seen by an observer at an anchorage, that may be found in Engineering News, vol. 25, page 610, June 27, 1891. The trusses consist of a three-hinged arch between the towers, the tension of which is resisted by trusses at each side also hinged at the ends where they are connected to the eye-bars in the anchorage. The eye-bar cables are stiffened by a system placed beneath them having a chord parallel to the cables and connected to them by bracings that forms isosceles triangles. The lower chord is composed of stiff members

Fig.15 Suspension Bridge over Mill Creek Valley and Railroad Tracks, Grand Avenue, St. Louis, 1891

throughout. The main span between centers of towers is 400 feet long, while the end trusses have spans of 150 feet. Mr. G. Koepcke secured rigidity in the Loschwitz Bridge, near Dresden, by using stiff members, and it is therefore sometimes called a cantilever. It has a central span of 481 feet and two side spans of 202 feet, with metal towers carrying a platform 36 feet wide. It is conspicuous for its bright color of cobalt blue and is sometimes called the "Blue Wonder".

Many of the largest suspension bridges in the United States span the Ohio River and its tributaries. A very interesting one over the

Ohio River at East Liverpool, Ohio, is of the stiffened suspension type. The main bridge consists of three spans; the Ohio, 360 feet long; the Channel 705 feet, and the West Virginia, 420 feet long. It has iron towers rising to a height of 60 feet above low water. The cables are built of seven strands of two hundred No. 8 B.W.G. oiled steel wires 1515.5 feet in length. It was opened to traffic in 1897. Another bridge at Rochester, Pennsylvania has a center opening of 800 feet, and side spans of 400 and 416 feet. The roadway is 22 feet wide including one 7 foot walk. It has wire cables and is stiffened with steel trusses 18 feet deep. Similar to this was one proposed by Herman Laub in 1897, to cross the Ohio at Bellaire, with a center span of 850 feet, but it was not carried out. A very attractive one over a tributary of the Ohio River is about two miles from Valley Jundtion, crossing the Whitewater River with a span of 498 feet. It has ornamental stone towers 12 feet square at the base and 36 feet on centers, transversely with a 20 foot clear roadway between them. The end cables are not loaded and the floor is braced with stays in the four quarters and held laterally with guys fastened to anchor blocks on shore.

The Langenargen suspension on Lake Constance is of the stiffened cable type. It was designed and built by Kubler in 1898. There were two cables $5\frac{1}{4}$ inches in diameter made of six twisted wire ropes, cradled from 22 feet apart at the center to 32 feet over the stone towers. The Muhlenthor Bridge over the Elbe-Trave Canal at Lubeck (1899) was stiffened by means of lattice ribs below the floor.

Between the years 1900-04 two suspension bridges were erected crossing the New River in West Virginia at Nuttalburg and Caperton. The first had a span of 340 feet supported by four cables $1\frac{1}{4}$ inches in diameter with masonry towers 22 feet high. The Caperton bridge has a span of 510 feet and wood towers $19\frac{1}{2}$ feet on centers, transversely, and 35 feet high, sheathed over and shingled. The bridge had one $1\frac{1}{2}$ inch cable on each side.

In 1900 a very unusual suspension footbridge was erected over the Lehigh River and Canal at Easton, Pennsylvania. It was designed by H. G. Tyrell and joins Dock Street on the lower side of the river with Glenwood Avenue on the upper side, 90 feet above it. This great difference in elevation was overcome by making the floor descend on a grade of 7.2 per cent from

the upper bank to meet a stairs rising from Dock Street at the lower side. The bridge has two river spans of 279 feet, supported on steel towers 108 feet high, and a small tower at the upper end from which the cables pass over Glendon Avenue to their anchorages, the total length being 8o4 feet. The cables are 2 3/8 inches in diameter, with a sag of 1/10 the span.

Four years later another interesting one known as the Ticonic suspension foot bridge (Fig.16) was erected at Waterville, Maine,

Fig.16 Ticonic Suspension Bridge over Kenebec River, Waterville, Maine, 1903

carrying East Temple Street over the Kennebec River, with a center span of 400 feet. It was 6 feet wide and the distance between towers, trans-

versely, was 20 feet. There are two 2 3/8 inch cables, one on each side. The towers are 72 feet high above the water.

During this time several interesting suspension bridges were erected in Europe. The Shwur-Platz Bridge crosses the Danube at Budapest. It had a central span of 951 feet and two side spans of 145 feet each. The iron towers rest on cast steel hinged bearings. The roadway is 59 feet wide carrying two tram lines. The Bonhomme suspension bridge crosses the River Blavet midway between Hennebout and Lorient. Tt has a total length of 778 feet, one central span of 535 feet and two short spans 121 feet each. The roadway is 88 feet above high water. The main span may be considered as divided into three parts, the central portion being hung from five continuous cables on each side, and the two end portions 118 feet long hung from six diagonal cables on each side. The towers are 148 feet high above high water. Another suspension bridge (Fig.17) crosses the River Rhon at Vernasion, France, 8½ miles below Lyons. It has a center span of 763.6 feet with side spans of 172 feet and 139 feet. The width of the roadway is 16.8 feet supported by twenty-four cables of wires in concentric layers and alternately twisted. Each cable is composed of one hundred and

Fig.17 Vernasion Bridge over River Rhon, France

twenty-seven wires, each wire having a diameter of .146 inches. Another bridge is the Pont Lorois over the Etel on the road from Pont Lorois to Auray. It has a single span of 360 feet, and the floor is 40 feet above water. It was blown down in 1894.

The Elizabeth eye-bar suspension bridge (Fig.18) which crosses the Danube in a single span at Budapest is a model of elegance and simplicity. The main span from center to center of piers is 957 feet in length. The roadway consists of a driveway 36.3 feet wide, and two footways, one on each side. The suspension chains are arranged in two pairs 66 feet apart, pivoted at the base and enclosed by masonry. It was

Fig.17 Suspension Bridge over River Tarn, France

twenty-seven wires, each wire having a diameter of .116 inches. Another bridge is the Pont Lorois over the Etel on the road from Port Louis to Quiberon. It has a single span of 600 feet, and the floor is 90 feet above water. It was blown down in 1909.

The Elisabeth-Bridge suspension bridge (Fig.18) which crosses the Danube in a single span at Budapest is a model of elegance and simplicity. The main span from center to center of piers is 951 feet in length. The roadway consists of a driveway 36.1 feet wide, and two footways, one on each side. The suspension chains are arranged in two pairs 36 feet apart, anchored at the ends and enclosed by masonry. It was

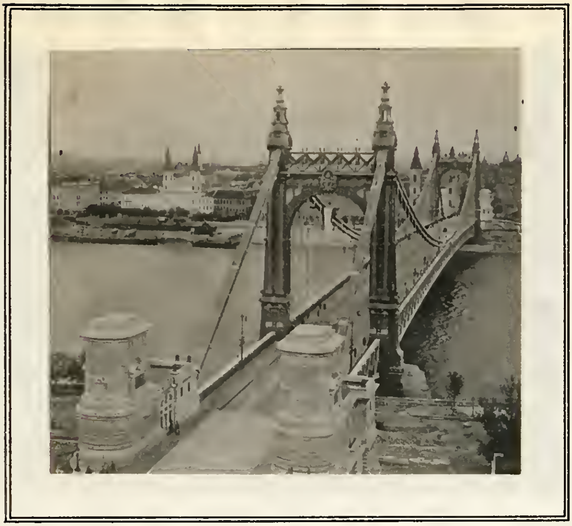

Fig.18 Eye-Bar Cable Suspension Bridge over the Danube River at Budapest, Hungary

designed by Aurelius Czekelius, engineer, and M. Nagy, architect.

In 1909 the Diroontah suspension bridge (Fig.19), the first metal bridge to be erected in Afghanistan, was opened to traffic. The structure spans the Kabul River at the mouth of the famous Diroontah Gorge about seven miles from Jallahad. The span is 396 feet between tower centers with a clear width between parapets of 10 feet. It was designed for pedestrian and light vehicular traffic.

Fig.19 First Metal Bridge in Afghanistan

The Kaiserbruecke over the Oder River at Breslau, Germany, was built in 1910. It has a span of 415 feet and is used for highway purposes. The supporting chains are pairs of flat bands composed of six layers of steel plate(bands) riveted together, having four bands for each chain. The chains are 65.6 feet apart center to center. Another interesting bridge was built about this time in France. It was a water-conduit suspension bridge crossing the River Loire at the Village of Feuers, France, and carries a conduit across the river to the town. The main suspension for the conduit was made of two cables suspended from anchors fastened to the sides of

a central tower and crossing to the opposite side of the shore towers. The conduit was slung from these cables by means of crossed smaller cables attached to cross-bars bolted tight to the main cables. The central tower had already been in service on a highway suspension bridge at the site.

The question of bridging the Rhine between Cöln and Dentz had been under consideration for more than ten years, but it was only in July, 1911 that tenders were invited by the Municipality of Cöln for the construction of a new street bridge to replace the then existing pontoon structure. The resulting competition led to no definite selection, and a second call for designs limited to the five firms having the best "first" designs was initiated early in 1912 with the result that the design submitted by the Maschienenfabrik Angsburg-Nürnberg was recommended for adoption. It was accepted at a price of about seven and one-half million marks. The bridge is a self anchored suspension bridge. The chains, instead of being led to land anchorages, as is customary, they are anchored by bolts to the stiffening girder itself, thereby putting the girder under compression. The middle span is 605 feet long and the two end spans each one half of this or 302½ feet. It has a width between

trusses of 62.6 feet center to center and a roadway 36.7 feet throughout. The chains are made of 6 inch nickel steel eye-bars and have a versed sine of 16½ inches. The number of bars in each cable varies from six to twelve; their thickness ranges from 7/8 to 1 inch.

A new suspension bridge erected in 1912 crosses the River LaGrasse at Massena Center, St. Lawrence County, New York. It is a three span structure with a main span of 400 feet and two side spans of 100 feet each. All the spans are suspended from two cables, each cable being made up of seven strands each 1½ inches in diameter. The cables are cradled and the versed sine of the main cables from center to center of towers is 38 feet. The towers are spaced 25 feet apart on centers and are 65 feet high. The stiffening trusses are 16 feet on centers and are 8 feet 3½ inches deep.

A novel suspension bridge crosses the Danube River near Passau, a city on the frontier of Austria and Bavaria. The novel feature of this bridge is the anchorage of one end of the cable to a high rock bluff on the side of the river, thus dispensing with the use of the usual tower. The span is 414 feet and the distance between anchorages is 681 feet. The sag of the

cable is 40 feet and the roadway is 21 feet wide.

In 1913 L. H. Chase proposed a highway suspension bridge to cross the Mersey River at Liverpool, England. It has a main span of 2700 feet, towers 500 feet high and a width of 50 feet between trusses, and a clear height of 200 feet above water. It is proposed to support the towers 300 feet apart transversely and cradle the cables in planes intersecting 20 feet above the roadway at the approximate vertical center of wind pressure, thus securing great lateral stability. A novelty, however, is in the approaches to be $4\frac{1}{2}$ turns of a helical roadway contained in a hollow cylindrical reinforced concrete tower, 200 feet in diameter.

A recent electric railroad bridge with a central span of 156 meters, and two side spans of 39 meters, was built at Villefranche-de-Confluent. It is somewhat similar to the Ordish principle and has a platform supported by a system of cables running straight from the panel points of the floor to the top of the tower. Several similar to this, of the Gisclard type, in spans up to 42 meters, have been exported and erected in French Congo.

About the year 1914 a suspension bridge was built near Hazelton, Western Canada, by wire rope manufacturers and engineers of Wakefield, England. It is of the Stiffened suspension type and has a span between tower centers of 451 feet. The bridge platform is suspended 250 feet above the river by main cables, 2 7/16 inches in diameter, of locked coil construction. The suspender rods are spaced at intervals of 4 feet. At each end of the bridge there are frame towers 68 feet high. This bridge was constructed for vehicular and pedestrian traffic.

Fig.20 Indian Built Bridge across the Bulkley River, Hazelton, Western Canada

Beneath the bridge is the suspension bridge Fig.20 built by Indian trappers about 1898. The struc-

ture is a cantilever and suspension combination built mainly of round poles, telegraph wire and wooden pins; few nails being used. The telegraph wire used in the construction is said to have been obtained from a quantity left by Col. Bulkley's party. Col. Bulkley was the builder of the telegraph line intended to connect Europe with America, by cable across the Behring Strait, which project was abandoned in 1867 when the first trans-atlantic cable was laid. The platform is suspended from a large steam boat cable obtained from the Hudson Bay Co. The travel across the bridge consists mainly of trappers and their outfits. It is still open to traffic.

A new highway crossing of the Ohio River was put into service April 29, 1916. It is a suspension bridge between Parkersburg, West Virginia, and Belpre, Ohio, and is located 280 feet below the Baltimore and Ohio Railroad crossing. The total length of the bridge is 2,856 feet consisting os three suspended spans, 375, 775, and 275 feet in length. It has two electric railway tracks in a 22 foot roadway and one 6 foot sidewalk. Each cable has an area of 40.8 square inches net and contains seven strands of No.8 wire. The stiffening trusses are 21 feet deep and spaced 24 feet center to center. The towers are

made of eight open columns, braced in fours to form two pedestals, and anchored well down into the piers.

An interesting bridge was recently built across the Rogue River at Agness in Curry County, Washington, with wire fencing instead of the usual cables as suspension members. The bridge is 659 feet long from anchorage to anchorage including a span of 380 feet over the water. The fencing used on the sides has a No. 7 top wire while the second and bottom wires are size No.9 and the seventeen intermediate wires are size No.11. The flooring consists of a field fencing with No.9 wires at each edge and eight No.11 intermediate wires. The piers and anchors for the bridge are cedar logs hewn out with an ax.

A remarkable suspension bridge used for pedestrian travel crosses Pincher Creek at Alberta, Canada. It was designed and erected without the services of an engineer by a member of the town council at a cost of $90. The span was 160 feet. The posts carrying the cables are about the size of ordinary telegraph poles. The anchorage at one end is a cotton-wood stump and at the other end 5/8 inch round iron rods driven into the ground. The footwalk is carried on five strands of woven-wire fencing suspended on each side by

eleven uprights of 3/16 inch galvanized iron wire attached to each cable. The cables are made of 1/8 inch wire passing over saddles of $\frac{3}{4}$ inch pipe passed through auger holes in the posts. The most remarkable thing about this bridge is the small size and wide spacing of the suspenders, one of which was broken in 1913. This, however, does not prevent a passage in safety.

For many years the Hudson River, near New York City, has been the scene of the erection of monumental works in the art of bridge building. Here the most notable suspension bridges have been built, namely the Brooklyn, the Williamsburg and the Manhattan bridges. The Brooklyn Bridge (Fig.21) crosses the East River from Park Row to Sands and Washington Streets, Brooklyn, and is the first and most conspicuous from lower New York and from the Harbor. The preliminary investigations for this bridge were made in 1850-55 under the direction of John A. Roebling. Mr. Roebling did not live to see the completion of the bridge. After his death the construction was carried to completion by his son, Col. Washington Roebling. The main span is 1595 feet 6 inches and each of the land spans from the center of the towers to the face of the anchorages is 930 feet. It was completed in 1883

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For many years the Hudson River, New York City, has been the scene of the erection of monumental works in the art of bridge building. Here the most notable suspension bridges have been built, namely the Brooklyn, the Williamsburg and the Manhattan bridges. The Brooklyn Bridge (Fig.31) extends from the City Hall Park to Sands and Washington Streets, Brooklyn, and is the first and most conspicuous from [illegible] and from the [illegible]. The preliminary investigations for this bridge were made in 1866-69 under the direction of John A. Roebling. Mr. Roebling did not live to see the completion of his design. After his death the construction was carried to completion by his son, Col. Washington Roebling. The main span is 1595 feet 6 inches and each of the land spans from the center of the towers to the face of the anchorages is 930 feet. It was completed in 1883.

and was the first bridge of the suspension type in which steel was used for the cables, suspenders, stiffening trusses and floor system. The total height of the under side of the bridge above mean high water is 133 feet. The width is 85 feet

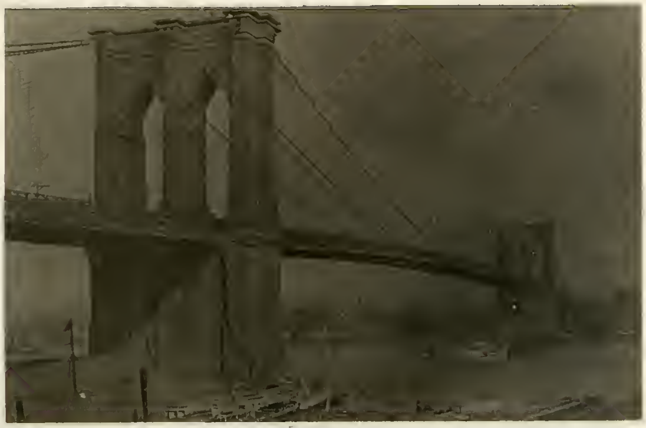

Fig.21 Brooklyn Bridge over East River, N. Y.

and provides for two elevated railroad tracks, two trolley tracks on the two 18 foot highways, and a center way of 15 feet for pedestrians. The two massive masonry towers are carried up to a height of 272 feet above the river. The platform is supported by four main cables $15\frac{3}{4}$ inches in diameter with a sag of 128 feet. The stiffening trusses have on several occasions been buckled and broken, but of late years, the bridge has been subjected to careful and continued scrutiny by competent engineers, and, so long

as this is done, no fears need be entertained for the safety of the structure. The bridge has been recently stiffened and the floor system completely rebuilt so that the bridge as it is now will be good for many years if it is safe-guarded by frequent painting and careful all around maintenance.

In 1894-5 work was commenced on another

Fig.22 Williamsburg Suspension Bridge over East River, 1904

suspension bridge known as the Williamsburg Bridge (Fig.22). The location of the crossing was laid from Delancy Street, Manhattan, to Broadway in Brooklyn. The main span of this bridge has a clear length of 1600 feet, and compared with its predecessor, the Brooklyn Bridge,

it is a much larger structure, the suspended roadway being 120 feet in width. It carries two elevated tracks, four trolley tracks, two 18 foot passenger foot-walks between trusses, and two 20 foot roadways outside of the trusses, carried on cantilever extensions of the floor beams. The underneath clearance for the passage of ships in the central 400 feet is 135 feet. The bridge is stiffened by two unusually heavy trusses, each 40 feet in depth, extending continuously from anchorage to anchorage. There are four main cables, each of which is $18\frac{3}{4}$ inches in diameter, passing over the steel towers carried to a total height of 335 feet above the river. The cables for supporting the roadway are attached to the main cables by means of heavy cast-iron saddles, and at their lower ends they are looped around cast steel shoes, from which the floor b beams of the bridge are hung by four heavy steel bolts. It has the largest traffic of any bridge in existence, and is surpassed in length only by the Forth Bridge in Scotland. The total cost of the bridge including the approaches and purchase of real estate, was about $22,000,000.

The third of the great crossings of the East River, known as the Manhattan Bridge, is located about a quarter of a mile to the east of the old Brooklyn Bridge. It has the largest carrying capacity of any bridge in existence. Originally designed as a stiffened chain-cable bridge, the plans were subsequently changed by the substitution of wire for chain cables, which change was caused by a change in administration. The lower deck has provision for four surface tracks, one 35 foot carriage way and two 11 foot walks, and the upper deck has space for four elevated railroad tracks. The platform is carried by cables $21\frac{1}{4}$ inches in diameter hanging in vertical planes. Each cable contains thirty-seven strands of 256 wires each, so that there is a total of 9,472 wires in each cable. The cables are supported by towers consisting of four apparently slender but exceedingly heavy and stiff columns that rise 322 feet above the water level. It was opened to travel in December, 1909, and the total cost was about $26,000,000.

For fifteen years or more the proposed crossing of the North or Hudson River, with a span of 3100 feet has been seriously considered. It would exceed any suspension yet projected, though a cable span of 4427 feet between towers,

consisting of four 7/8 inch galvanized steel wire cables is in use at the Straits of Carquinez, California, 140 miles from Oakland, for the transmission of power, with a clear head-room beneath it of 200 feet. At least five designs for the proposed North River Bridge have appeared, with estimated costs of seventeen to thirty seven million dollars. Of these the crossing at or near Fifty-seventh Street is evidently the most desirable from a traffic stand point as New Jersey naturally desires the bridge to be as far south as practicable to accomodate the large centers of population. This situation is also the most central in New York, and practically opposite the Queensboro Bridge over the East River, thus(gainin) giving a through line of travel from Long Island to New Jersey. The design for this structure followed closely Lindenthal's eye-bar design for the Manhattan Bridge, (described in Eng. News Feb. 26, 1903 p. 183, and subsequently not built.) The towers are of steel and the bridge is located with its axis half way between Fifty-seventh and Fifty-eighth Streets.

As material for suspension bridges is comparatively light and more easily transported than riveted structural work, many bridges of this type have been erected in foreign countries.

One of the largest of this kind is the Occident suspension at Antioquia over the Cauca River, Columbia, South America. This bridge has a span of 940 feet, with the small cable sag of 30 feet. The bridge is 12 feet wide, and has two 4 inch cables at each side with hollow towers, the lower 12 feet of which are of brick surmounted with timber frames. It is one of the very lightest bridges ever made and is remarkable for its extremely flat cables. Another bridge in Columbia over the Guarino River at Honda has a span of 130 feet, a roadway 12 feet wide and towers 16 feet high made of iron pipe filled with concrete. In the years 1895 to 1900 H. G. Tyrell made several designs of suspension bridges for export to Mexico and South America, mostly in short spans of 250 feet. In 1900 a suspension bridge with a span of 1.030 feet was erected for the Spanish Silver Mines at Mampimi, Mexico, over the Ojuela River. It was supported by two wire cables on timber towers 50 feet high, and on 30 foot centers. Each cable consisted of three two inch steel wire ropes. There are four stays in each quarter. Across the Rio Chiriqui in Panama there is a suspension highway bridge with a single span of 410 feet. The cables are four 2½ inch wire ropes pulled across the

One of the largest of this kind is the [illegible] suspension at [illegible] over the [illegible] River, Colombia, South America. This bridge has a span of 920 feet, with the small cable sag of 30 feet. The bridge is 15 feet wide, and has two 4 inch cables at each side with [illegible] towers, the lower 15 feet of which are of brick surmounted with timber frames. It is one of the very lightest bridges ever made and is remarkable for its extremely flat cables. Another bridge in Colombia over the [illegible] River at [illegible] has a span of 160 feet, a roadway 12 feet wide and towers 16 feet high made of iron pipe filled with concrete. In the years 1890 to 1900 [illegible]. C. [illegible] made several designs of suspension bridges for export to Mexico and South America, mostly in short spans of 300 feet. In 1890 a suspension bridge with a span of 1,000 feet was erected for the Spanish Silver Mines at [illegible], Mexico, over the [illegible] River. It was supported by two wire cables on timber towers 30 feet high, and on 30 foot centers. Each cable consisted of three two inch steel wire ropes. There are four stays in each quarter. Across the [illegible] there is a suspension highway bridge with a single span of 115 feet. The cables are four [illegible] inch wire ropes [illegible]

river on $\frac{3}{4}$ inch temporary cables. Considerable difficulty was encountered in transporting the four cables. The almost impossible task of securing experienced men to do field riveting on a small job in a new and isolated tropical country were vital factore in the further design. This choice of structure is due to the torrential nature of the river and was arrived at after a center pier in the course of construction for a two span suspension bridge had been washed out by a sudden rise of the water.

Suspension bridges have been erected in various parts of New Zealand and have withstood very severe practical tests, and have proved satisfactory in regard to their stability, simplicity, and comparative cheapness. The Kawaran suspension bridge over the River Kawaran has a span of 300 feet. The platform is 12 feet wide between the girders and is suspended 140 feet above ordinary water level. The cables were constructed by the Warrington Wire Rope Co., and are composed of twenty-eight galvanized steel wire ropes 4 7/8 inches in circumference, each rope consisting of six strands of several wires each with a core of hemp. The ropes are arranged in sets of four, two on each side of the bridge. The versed sine of the cables is 1/13 of the span and the cables are drawn together at the center

wires to a last temporary sling. Considerable difficulty was encountered in constructing the foundation. The almost impossible task of ex[illegible] [illegible] to [illegible] [illegible] a small job [illegible] and isolated [illegible] country were vital factors in the [illegible] design. This [illegible] of [illegible] is [illegible] to the tremendous [illegible] of the river and [illegible] a [illegible] in the course of construction for a [illegible] suspension bridge had been [illegible] but by a sudden rise of the water.

Suspension bridges have been special[illegible] [illegible] of [illegible] and were [illegible] [illegible] more practical tests, [illegible] proved [illegible] [illegible] stability, rigidity, and comparative economy. The [illegible] suspension bridge over the [illegible] River has a span of 700 feet. The platform is 12 feet wide between the [illegible] and [illegible] feet above ordinary water level. The cables were manufactured by the [illegible] Co., and [illegible] twenty-eight galvanized steel wire ropes [illegible] in circumference, each rope consisting of [illegible] strands [illegible]. The ropes are arranged in sets of [illegible], two on each side of the bridge. The [illegible] of the cables is [illegible] of the span and the [illegible] [illegible] of the [illegible]

about 6 feet forming horizontal as well as vertical curves. Violent wind storms which are frequent in the gorge have but little effect upon the structure. The Strath Taieri Bridge over the Taieri River at Strath, New Zealand, completed an uninterrupted road from Dunedin, the chief provincial town. The span between towers is 150 feet and the clear width between trusses is 14 feet. There are eight cables consisting of flat, plough-steel woven wire 3 x $\frac{1}{2}$ inches in sections made up of fourteen strands of seven wires each, and one similar interlacing strand. The towers are of ashlar masonry laid in 12 inch courses. The Upper Hut Bridge over the Maori River (Fig.23) has a span of 112 feet and a width of 12 feet. There are two 25 foot towers on each side of the river. The eight cables have a breaking strength of 75 tons each, the eight totaling 600 tons. The suspender rods are sixty-two in number, made of 7/8 inch iron and are attached to the main cables by clips at intervals of 5 feet. The Taoroa-Taihape Bridge has a clear span between towers of 253 feet, the deck being 270 feet above the Rangitikei River bed, near Taihape, North Island. Eight steel cables support the bridge and pass over two ferro-concrete towers on each side of the river. Two suspension bridges which span deep gorges some

the [illegible] feet [illegible] verti-
cal curves. Oblique wind bracing [illegible] fre-
quent in the gorge [illegible]
the structure. The [illegible] bridge over
the [illegible] River at [illegible], New Zealand, com-
pleted at [illegible] from [illegible], the
chief provincial town. The span [illegible]
is 150 feet and the [illegible]
is 12 feet. There are [illegible] cables consisting
of [illegible], plough-steel strand wire 3 [illegible] in
[illegible] made up of [illegible] strands of [illegible]
[illegible], and [illegible].
The [illegible] of [illegible] 12 inch
concrete. The upper [illegible] bridge over the [illegible]
River (Fig. 99) has a span of 111 feet and a
width of 12 feet. There are two 45 foot towers
on each side of the river. The [illegible] bridge
[illegible] of [illegible] tons each, the
[illegible] 400 tons. The [illegible]
are [illegible], [illegible] of 7/8 inch iron
[illegible] cables [illegible] at
intervals of 5 feet. [illegible] bridge [illegible]
has a [illegible] of 350 feet, the
[illegible] 270 feet [illegible]
[illegible], [illegible] land. [illegible] steel
cables [illegible] bridge [illegible] two [illegible]
concrete [illegible] on each side [illegible].
[illegible]

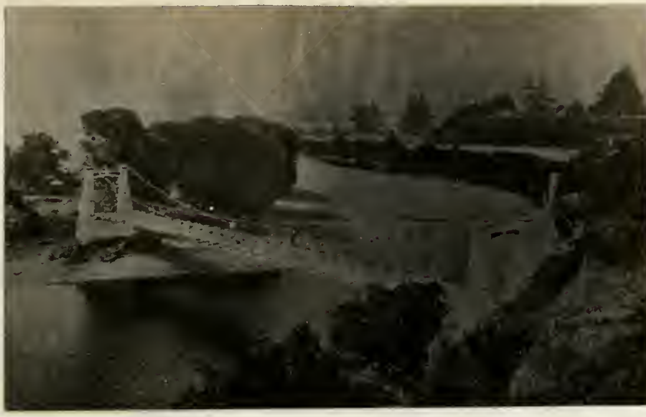

Fig.23 The Upper Hut Bridge over Maori River N.Z.

180 feet above the stream bed, are situated on the Seddon-Molesworth road, Awatere County, Marlborough, about twelve miles from the township of Seddon. The bridges are of similar design, and have spans of 96 feet (Fig.24) and 80 feet respectively. The anchor towers are of concrete. There are four cables 5 inches in diameter passing over the towers on a cast iron saddle with six iron wheels to each cable. The suspending rods that carry the bridge from the cables are composed of steel, 1 inch in diameter, and are spaced at intervals of 5 feet and fixed to the cables with clips. During the tests a 13 ton traction engine was driven onto the structures, and only the very slightest oscillation was

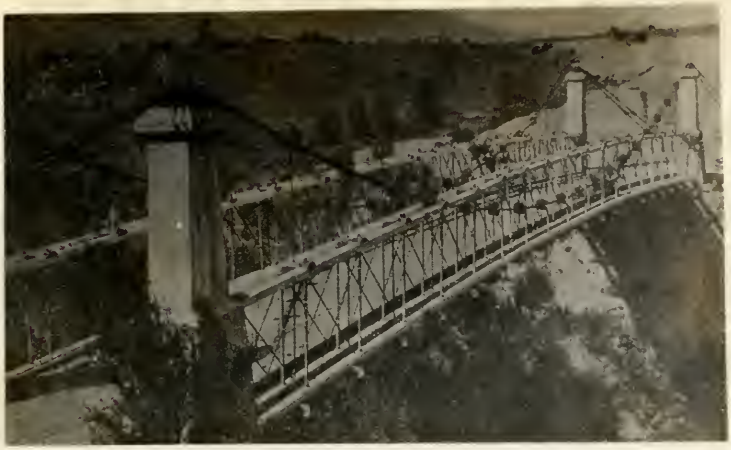

Fig.24 The Upton Downs Bridge, Atwatere County, Marlborough

visible while the engine was moving. It was stopped in the center of the bridges and tests of deflection were taken. With over 150 people on the larger structure, besides the engine, the deflection registered was $1\frac{1}{4}$ inches. The deflection of the shorter bridge was 1 inch. Two bridges were also built for the Wayawa County Council (Hawke's Bay) at Ashely, Clinton, one being 165 feet and the other 155 feet long. Eight cables passing over concrete towers support the floor in both bridges. Each bridge is practically all concrete, steel and iron, and the total weight of the structure on the cables is about 52 tons.

As suspension bridges can be erected in a comparatively short time, they have frequently been used as temporary structures to replace others which have been washed away. They were used at Kansas City after the flood of 1904, and one was erected over the Tiber at Rome where two arches of Ponte Rotto were swept out. Another at Rome (1889) has stiffened cables somewhat like those of the Point Bridge at Pittsburg. A temporary suspension bridge was used for filling in a high embankment at Lone Tree Creek on a diviation of the Union Pacific Railroad, in the Rocky Mountain district. The bridge consisted of four main cables of steel, each $2\frac{1}{2}$ inches in diameter, spaced at 2 foot centers. The clear span between towers was 300 feet and the deflection when fully loaded was 44 inches. It also had an auxilliary cable on each side $1\frac{1}{2}$ inches in diameter, the two being 15 feet apart. Steel guy wires were secured to the road at 30 foot intervals and anchored to the side of the canyon. These guys served to check lateral oscillations. Car loads of earth were run out on the bridge, and the dirt dumped into the valley below. One accident occured during the construction, when a train of fifteen cars fell into the valley below. Another bridge of this type was used in

constructing a high embankment near Freiburg, Switzerland, across two narrow but unusually high ravines. The lengths of crossing respectively were 345 feet and 360 feet. The cables consisted of a single wire rope each, supported on wooden portals frames 20 feet high, and anchored to the platforms weighted with stone. The deflection of the bridge under load was sometimes as much as 3 feet. The total cost of this structure was $1600. A suspension bridge across Placer River Canyon, 52 miles north of Seward, Alaska, on the line of the Alaska Central Railroad was built to give foot passengers from the camps access to tunnel work on the other side of the canyon, and to carry air pipe lines from the compressor. It had a span of 120 feet and the platform was supported by two $\frac{3}{4}$ inch cables at an elevation of 125 feet from the bottom of the canyon. After its erection two other $\frac{3}{4}$ inch cables were added to stiffen the bridge laterally. A temporary foot-bridge of the suspension type was erected in the town of Sulphur, Oklahoma, in the Platt National Park. It was designed by Mr. H. V. Hinkley, consulting engineer and constructed under the direction of Mr. Albert R. Green, Park Superintendent. It has a span of 120 feet and the total cost was $950. During

construction of the Panama Canal, a highway suspension was erected across the Panama Canal Cut at Empire, C. Z., with a span of 600 feet. The main cables were 870 feet in length, made of galvanized crucible steel $2\frac{3}{4}$ inches in diameter, two on each side. The towers were of creosoted timber and 60 feet high. It was opened to traffic on July 31, 1909, six months after construction was started. It was built to carry pipe lines and water mains across the Culebra Cut for operating drills and steam shovels along the east side of the cut. Temporary suspension bridges were used to cross the Speedway at Indianapolis, and at Youngstown, Ohio. The Speedway Bridge had a span of 80 feet and crossed over the track from the grand stand. It was of very light construction. The Youngstown Bridge crosses the Mahoning River at Northwest Avenue and is only 16 feet wide. It replaces the old fixed bridge washed out by the great flood of March, 1913, and its emergency successor, the pontoon bridge, which was carried away.

A number of very artistic suspension bridges may be found in the parks of Boston, Chicago and San Francisco. A small suspension in Mill Creek Park, Youngstown, Ohio, with stiff eye-bar cables was built in 1894 and is the work

of Charles E Fowler. The span is 90 feet between towers and the roadway 20 feet wide, with two walks of 5 feet each. Boston has a very artistic bridge of this type over the lagoon in the public gardens, adjoining the Boston Commons. More recent ones are in Garfield Park, Chicago, and in Golden Gate Park, San Francisco. In 1887 several young men erected a suspension bridge across the Desplaines River at Oak Park, Illinois. It was an unusual foot-bridge (Fig.25), with a span of 125 feet. Four cables 5/8 inch in dia-

Fig.25 Curious Foot-Bridge across the Desplaines River at Oak Park, Illinois

meter, hung between two trees for towers on opposite banks, supported the floor. The United States Forest Service has used the suspension

type of bridge to span the deep canyons in the National Forests of the Northwest. Seven suspension bridges have been built in the States of Oregon, and Washington, in recent years. In the case of the Thunder Creek Bridge, a suspension bridge with a 96 foot span, the heavy snows of the region made it necessary to design for a snow load of 125# 1 square foot. The cables were two wire ropes $1\frac{3}{4}$ inches in diameter and the cost of the structure was $2500. One at Skagit River, near Ruby Creek, replacing an old wooden truss erected at the site by miners, had a span of 84 feet, but stands 150 feet above water. The towers were founded on rock cliffs at the entrance of what is known as Canyon Diablo. The Wenatchee suspension bridge has a span of 190 feet between towers and is located three miles northeast of Chewaukum, Washington, a station on the Great Northern Railroad. The towers are 38 feet high and support two cables made of $1\frac{1}{2}$ inch crucible-steel with wire centers. The floor of the bridge is supported by $\frac{1}{2}$ inch rods and 3/8 inch cables fastened to the main cables by $1\frac{1}{2}$ inch Crosby clamps at intervals of 6 feet. The Cowlitz River is crossed by a suspension bridge having a span of 180 feet center to center of towers. The towers are of hewed timber built on cribs 18

feet high. The cables are two $2\frac{1}{4}$ inch crucible-steel ropes with wire centers. One anchorage is in solid rock while the other is a solid block of concrete, weighing approximately thirty-seven tons.

In the earlier types of suspension bridges the floor was directly suspended by hangers to the main cables so that a load at any point would cause a further sagging or deflection in the cable at that point and a rising at other points. This produced a wave motion in the floor as the load proceeded across the span. This lack of rigidity prevented, to a large extent the adoption of the suspension bridge where heavy live loads were to be carried. To overcome this, the floor system was at first modified by using long floor joists extending over several panels and adopting stiff and rigidly braced hand rails, thereby distributing the load to a larger portion of the cables. Following this, stiffening trusses were introduced which ran the full length of the span and were attached at regular intervals by hangers to the cables. The lack of rigidity combined with the inadequate allowance for stresses due to wind action has been the cause of the greater portion of the failures of this type of bridge.

Although the theory of the stiffening truss has been greatly improved in recent years, and the flexibility so noticeable in earlier designs has largely disappeared, as a consequence, there is still a big field for the present generation of engineers to cover before the suspension bridge is brought to its highest development and the theory of its action is as nearly as possible perfect.

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Am. Soc. C. E.	American Society of Civil Engineers, Transactions
Can. Eng.	Canadian Engineer
Eng. & Contr.	Engineering and Contracting
Eng. & Min. J.	Engineering and Mining Journal
Eng. N.	Engineering News Record
Eng. Rec.	Engineering Record
Inst. C. E.	Minutes and Proceedings of the Institution of Civil Engineers

J. Fr. Inst.	Journal of the Franklin Institute
Sci. Am.	Scientific American
Sci. Am. S.	Scientific American Supplement
W. Soc. E. J.	Journal of the Western Society of Engineers

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